SNAP TECHNOLOGY RISK / OPPORTUNITY ASSESSMENT
ADVANCED STUDIES / PRECONCEPTUAL PHASE

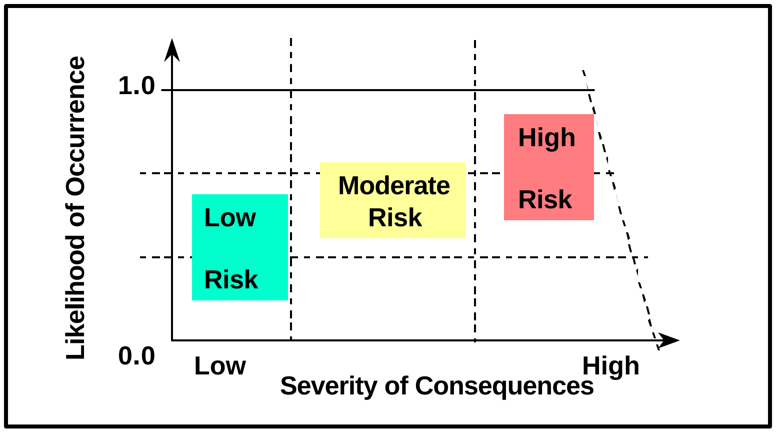
(Work In Progress)
January 2001

(E. Kujawski / SNAP System Engineering Group)

Risk/Opportunity Management

"For any project we may identify three major variables: performance, cost and schedule. The specification of any two will cause variation in the third."
The Heisenberg Extended Uncertainty Principle

Any project with high performance requirements, schedule and budget constraints incurs some risks of not achieving the technical, cost, or schedule objectives. The challenge is to achieve the proper balance between risk and opportunity and not avoid all risks. The key objective of the Conceptual Design Phase is to have a logically consistent set of requirements, costs and risks before committing to implement the system. The SNAP technical risks identified in the Pre-Conceptual Phase drive the R&D plan.



"A single number is not a big enough concept to communicate the idea of risk."

Good risk management will not prevent bad things from occurring. But, when they do, good risk management will have anticipated them and will reduce the bad effects. On the upside, risk management should seek to exploit opportunities.

Use Concept and Design Phases to control risk while improving cost and performance through enabling and enhancing technologies

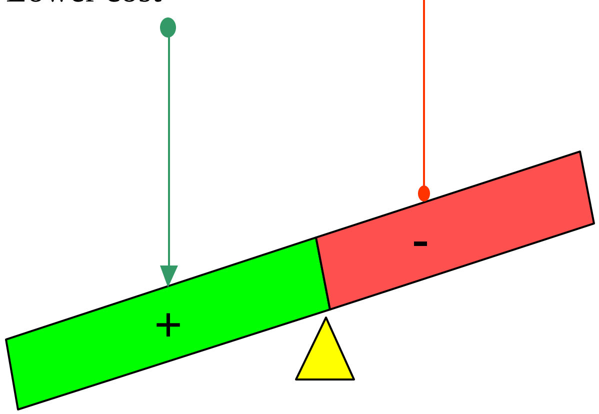
Improve Reward/Risk Ratio

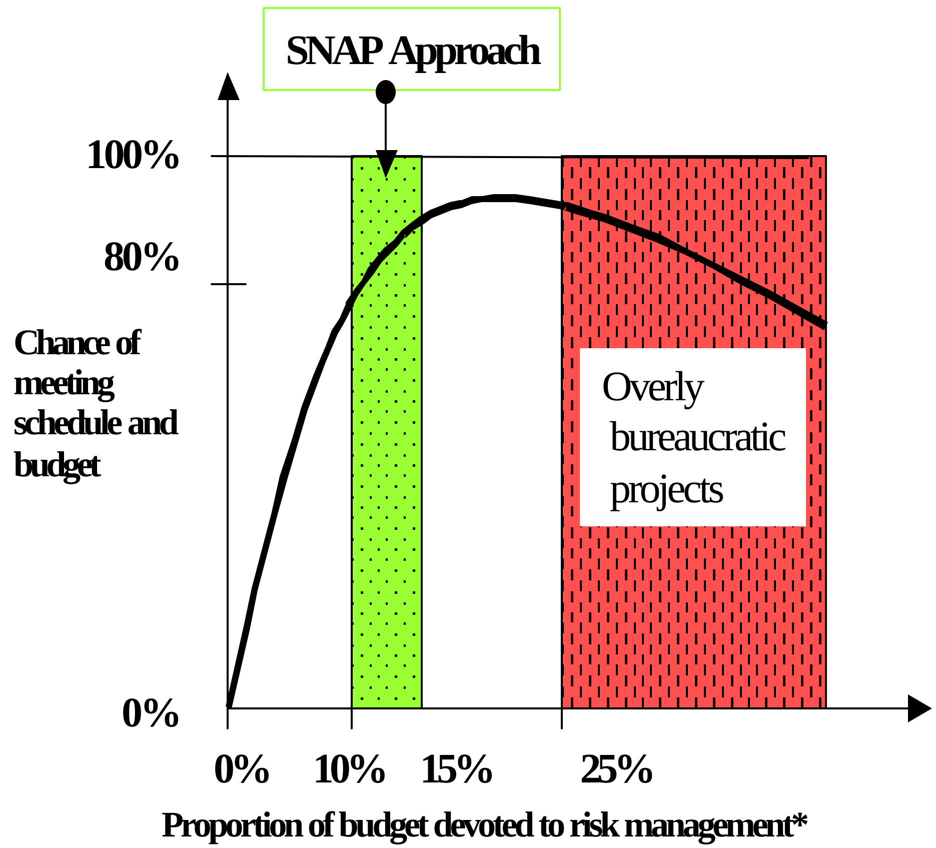
<u>Technology Development</u>

- More science
- Better data
- Lower cost

<u>Technical Risk Management</u>

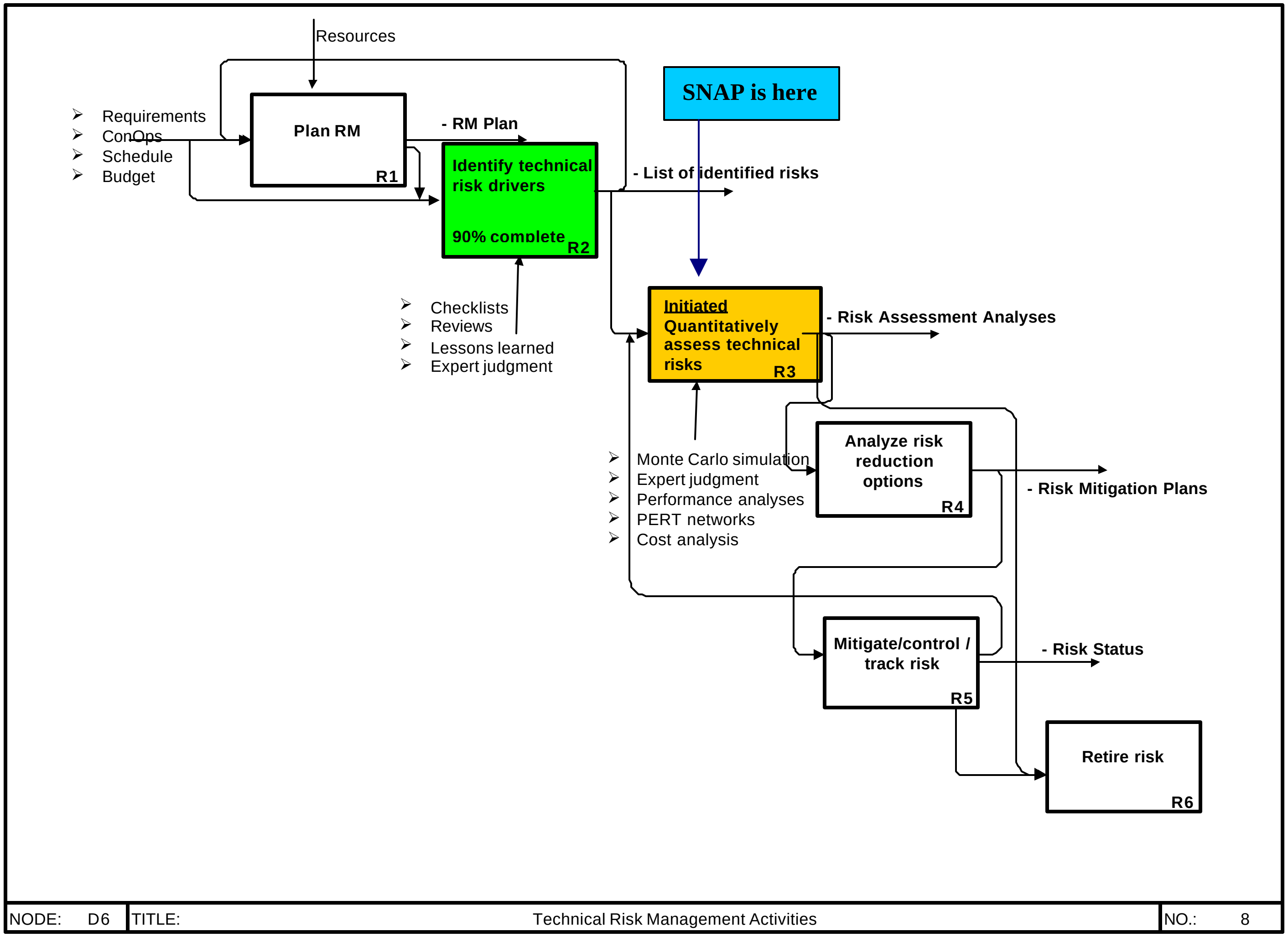
- Reduce uncertainty
- Reduce negative impact





*Steve McConnell Software Project Survival Guide, Microsoft Press 1998

Status of Technical Risk Assessment Activities



Description of Technology Readiness Levels

Technology Readiness Level	Exit Project Phase	Risk Reduction Activities	Exit Criteria Next Level and Phase
Level 1: Basic principles observed and reported.	Advanced Studies	Basic technology research.	- Basic principles observed and reported
Level 2: Technology concept and/or application formulated. Level 3: Analytical and experimental critical function and/or characteristic proof of concept.	Advanced Studies Conceptual Design	Research to prove technical feasibility. Active R&D initiated with analytical and laboratory studies.	- Technology concept and/or application formulated - Analytical and experimental critical function and/or characteristic proof-of-concept
Level 4: Component and/or breadboard validation in laboratory environment.	Conceptual Design	Technology development. "Low-fidelity" prototype implemented and tested.	- Demonstration of technical feasibility using breadboard in laboratory environment - Conceptual Design Report (CDR) - Systems Requirement Review (SRR)
Level 5: Component and/or breadboard validation in relevant environment.	Preliminary Design Detailed Design	Technology demonstration. Significant increase in level of fidelity. Basic technology elements integrated with reasonably realistic supporting elements. Prototype implementation conforms to target environment and interfaces.	- Component and/or brassboard validation in relevant environment. - Preliminary Design Review (PDR) at end of Phase B - Final/Critical Design Review (FDR) at end of Phase C
Level 6: System/subsystem model or prototype in a relevant environment.	Detailed Design Development	Major increase in level of fidelity. Prototype implemented on full-scale realistic problems. Partially integrated with existing systems. Engineering feasibility fully demonstrated in actual system application.	- System/subsystem model or production prototype demonstration in a relevant end-to-end environment (ground or space) - Not implemented for all technologies
Level 7: System prototype demonstration in a space environment.	Development	Fully integrated with operational hardware and software systems. All functionality tested in simulated and operational scenarios. End of system development.	- Actual system completed and "flight qualified" through test and demonstration (ground or space).
Level 8/9	Development Operations		- Actual system "flight proven" through successful mission operations

Why and How We Use Technology Readiness Levels (TRL)

- Technology Readiness Levels (TRL) 1-9 defined by NASA
- SNAP goal is for all high-risk items to reach TRL 5/6 by PDR.
- Projects reaching TRL 6 or higher by the start of Phase C/D stay within 15% of baseline cost estimates at the start of Phase C/D (NGST Science Instrument Technical Panel Report, 12/01/99)
- The line between the "technology risk factor " and the "design and engineering risk factor" is somewhat fuzzy since both involve development. The "technology risk factor" focuses on research and developing the application while the "design and engineering risk" focuses on the detailed implementation of the end-item.
- A project that reaches TRL 6 or higher by the start of Phase C/D is likely to stay within 15% of the baseline cost estimate made at the start of Phase C/D. (NASA analysis)

SOME DEFINITIONS

BRASSBOARD - An experimental device (or group of devices) used to determine feasibility and to develop technical and operational data. It normally is a model sufficiently hardened for use outside of laboratory environments to demonstrate the technical and operational principles of immediate interest. It may resemble the end item, but is not intended for use as the end item. It is normally built during Advanced Studies / Pre-Conceptual and Conceptual Design / Preliminary Analyses Phases and may be continued in the Preliminary Design Phase.

BREADBOARD - An experimental device (or group of devices) used to determine feasibility and to develop technical data. It normally is configured only for laboratory use to demonstrate the technical principles of immediate interest. It may not resemble the end item and is not intended for use as the projected end item. It is normally built during Advanced Studies or Pre-Conceptual and Conceptual Design Phases.

ENGINEERING PROTOTYPE - A development model of a unit that is close to production. The term may apply to circuitry, a device (black box) or a system, and may be in a breadboard (technical) configuration. The term may apply to a breadboard or brassboard configuration.

PRODUCTION PROTOTYPE - A final model of a design before the pilot unit is approved for production. It should be highly representative of final equipment, except that the exact manufacturing assembly process and production design changes may not yet be used or incorporated. It is suitable for complete evaluation of its electrical and/or mechanical form and may be in a brassboard (technical and operational configuration. It is normally built during the Detailed Design Phase and may be extended into the Development Phase.

PROTOTYPE - A model suitable for evaluation of design, performance, and production potential. Breadboards and brassboards are examples of early prototypes.

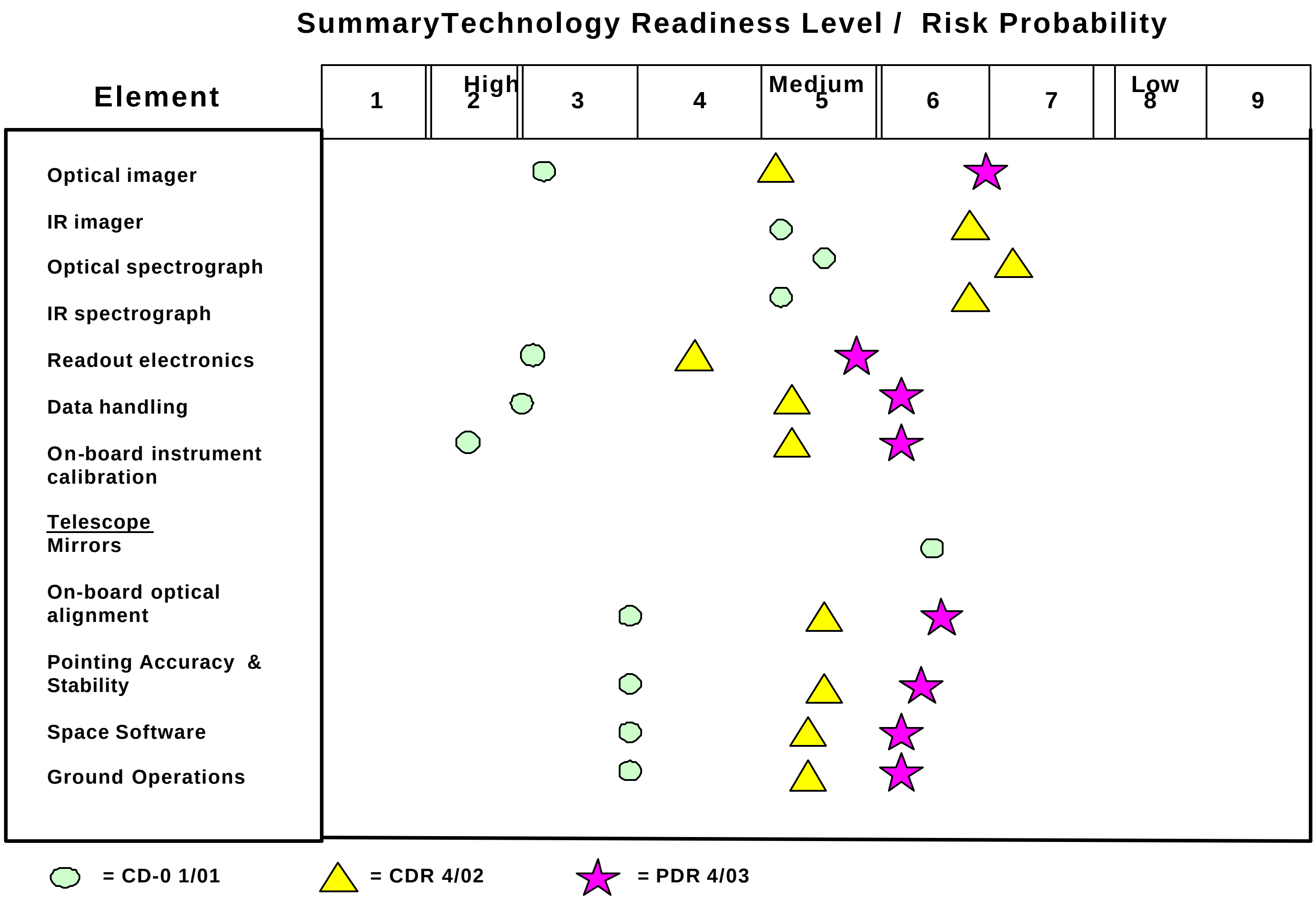
PROJECT CYCLES
- Pre-Phase A = Advanced studies = Preconceptual planning
- Phase A = Concept exploration = Conceptual design = Preliminary analysis
- Phase B = Preliminary design = Product/Program definition
- Phase C = Detailed design
- Phase D = Construction = Engineering and manufacturing development
- Phase E = Operations

Classification of Technical Risk Sources

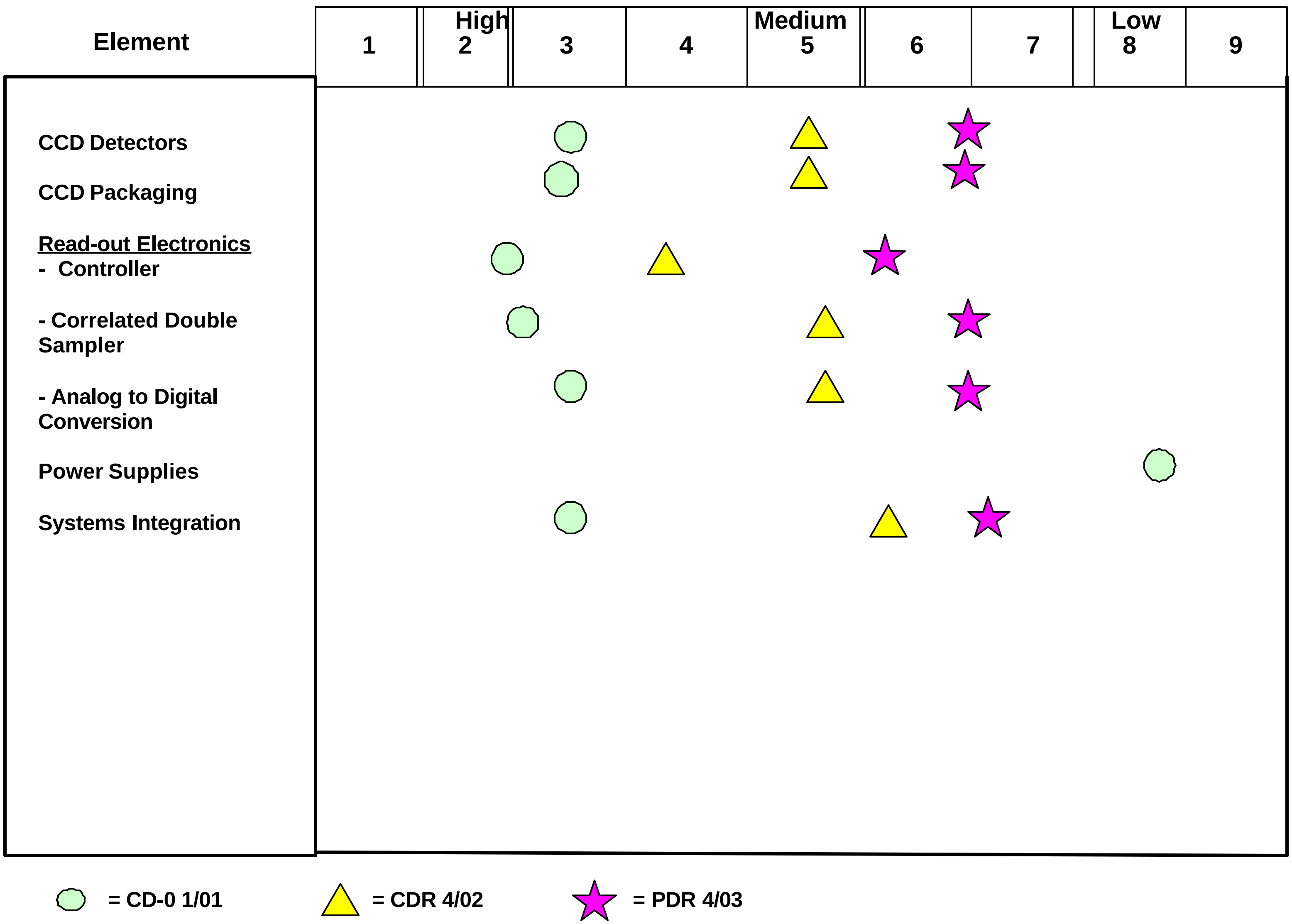
	Probability of Adverse Consequences		
Risk Category	**Very High – High 100 – 70%**	**Medium 70 – 30%**	**Low – Negligible 30 – 0%**
Technology	Technology Readiness Levels 1 – 3	Technology Readiness Levels 4 - 6	Technology Readiness Levels 7 - 9
Design & Engineering	- Volatile mission objectives. - Incomplete specifications with driving requirements as "TBD" and/or "TBR" - Major engineering development and/or breakthrough advance in design required. - Existing components do not meet constraints such as weight, power, radiation, and reliability. - Software algorithms need to be created/designed. - Highly dependent on the success of other projects.	- Few performance parameters are TBR and the supporting analysis is progress. No TBD parameters. - Design effort required using standard components within or slightly beyond accepted specification levels. - Software algorithms exist but need moderate modifications. - Slightly dependent on the success of other projects.	- All TBRs that drive the design have been resolved and supporting analysis is complete. - Simple and well-understood design using existing components within their qualification levels. - Independent of the success of any other efforts.
Manufacturing	- Manufacturing requirements exceed industry capability. - Production experience limited to the R&D environment - Highly dependent on the success of other projects	- Requires a combination of existing processes that meet requirements. - Slightly dependent on the success of other projects.	- Existing process meets requirements. - Independent of the success of any other efforts.

Integration and Test	- New test facilities and/or extensive changes required. - Many complex hardware and software interfaces - Custom and/or highly complex procedures - No work-arounds identified - "Big bang" integration at the end of the design process - Extensive reliance on complex analyses	- Test facilities available, moderate modifications required. - Hardware and software interfaces of medium complexity - Moderate concerns about work-arounds - Integration and test at subsystem level - Moderate concerns about mix of testing and analysis	- Test facilities available, few or no modifications required. - Standard procedures - Readily available work-arounds -"Piece-wise" integration

TBD: To Be Determined
TBR: To Be Resolved


SummaryTechnology Readiness Level / Risk Probability
Element
1
High
2
3
4
Medium
5
6
7
Low
8
9
Optical imager
IR imager
Optical spectrograph
IR spectrograph
Readout electronics
Data handling
On-board instrument calibration
Telescope
Mirrors
On-board optical alignment
Pointing Accuracy & Stability
Space Software
Ground Operations
= CD-0 1/01
= CDR 4/02
= PDR 4/03

Optical Imager & Readout Electronics
Technology Readiness Level / Risk Probability



Assessment of Risk Drivers
Pre-Phase A

Item	Issue	Risk Factor / Driver			
		Technology	Design & Engineering	Manufacturing	I & T
Optical imager detectors	New CCD developed at LBNL; 10.5 or 12.0 μm; stringent requirements; good yield important; limited in-house volume capability. Successful demonstration of 12.0 μm.	High	Med.	High	See below
Optical imager packaging	Wide FOV; mechanical alignment; thermal stability & uniformity; stringent flat fielding required; challenging integration with electronics.	Med.	High	High	High
NIR imager	Depends upon success of 1.7μm HgCdTe detectors for HST/WFC3. Thermal design is TBD. Intra-pixel variation may force a smaller plate scale. Less challenging than NGST large format, low noise IR detectors; NGST TRL (1/98 & 5/00) ~ 4.0 (notes 1 & 2).	Med.	High	Med.	Med.
Spectrograph	Exclusive of detectors. Several concepts under consideration; simpler than NGST-IFMOS. No dedicated technology development for NGST-IFMOS (Note 3). Risks associated with sensitivity to manufacturing process, design modifications for space	Low	Med./High	Med.	High

	qualification, and testing. Impact on operations and LCC need to be evaluated.				
Readout electronics (ROE) - Design	Only conceptual design. Power, thermal, weight, radiation, and reliability are design drivers. System-level testing required for risk mitigation.	Med.	High	See below	High
ROE – CDS ASIC development	Requirements prepared; DMILL process and schematic simulated. Power consumption and radiation are risk areas. Alternate technologies and processes to be evaluated. Schedule and cost risks are high.	Med.	High	High	Med.
ROE - Clock/bias/control ASIC development	Programmable design needs to be developed. Radiation issues need to be investigated. Single path identified; late start. Schedule and cost risks are high.	Med.	High	High	Med.
ROE - Commercial parts qualification	Baseline is to space-qualify a commercially available 16-bit ADC; 4 candidates identified. IC packaging and die are concerns. HESSI space-qualified Linear Technology ADC. Schedule and cost are concerns.	Med.	Med.	High	Med.
Data handling – Space and ground segments	~50 images comprised of ~ 200 exposures per day (> 100 GB per day). Prometheus orbit and MOC/SOC contact; high bandwidth; may require Southern Hemisphere ground station. Need space-qualified large memory arrays.	High	High	High	High

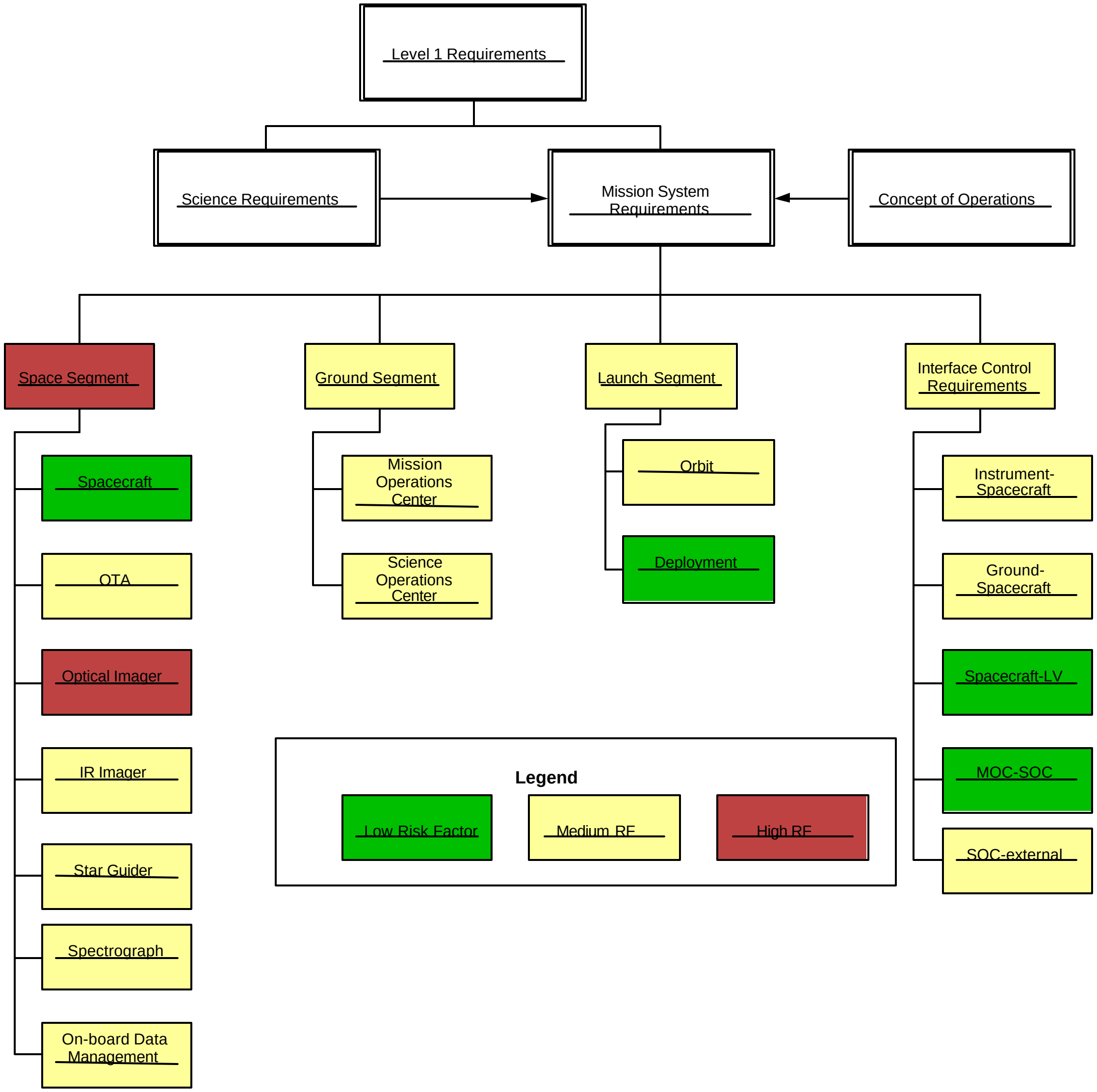
On-orbit calibration	Excellent photometric, wavelength, and astrometric calibration needed to deliver full scientific potential. Needed accuracy requires improvement to standard methods. Calibration identified as major risk element on NGST (note 4).	High	High	High	High
Star guider	High absolute pointing. Design star-guider for science pointing. Software to perform calibration. Risk is mitigated if detectors share common instrument focal plane.	Medium	High	High	High
Optical telescope assembly	No technology development required. Preliminary layout, structure design, and requirements complete; thermal analysis and specification TBD. 2.0 – 2.4m OTAs have flown. Long-lead item; end-to-end performance testing in 1-G; complex logistics.	Low	Med.	Med.	High
Filter wheel	A general concern is mechanism failure since this would impair ability to perform mission. Size of the filters and wheel is a concern. Several concepts including a fixed design have been proposed. Filter leak and operations need to be addressed. May impact design of star-guider (see note 5 and “pointing accuracy and stability”).	Low	High	Med.	Med.
Payload integration & test	Complex dependencies among spacecraft, OTA, and instrument. End-to-end testing desirable. Test Support Equipment (TSE) design is TBD. Test SNAP like operated on-orbit.	N/A	Med.	Low	High

Mass, layout, power	Preliminary mass, layout and power analyses completed. Adequate margin and contingency given standard bus and launch vehicles. Requirements creep is standard concern.	Low	Med.	Low	Low
Mechanisms	These include the filter wheel, shutters, release and deployment, mechanisms, valves,…Mechanism failures are always a concern. Probability of failure is controlled by design, manufacturing, and testing. Look for designs with no Single Point Failure.	Low	Low	Low	Low
Thermal design and stray IR	Rigorous design and analysis required to ensure OTA and instrument stability and alignment and minimize reflections. Wire routing and power dissipation require detailed analysis. System emissivity must be minimized for a warm telescope.	Low	Med.	Low	Low
Orbit insertion	Prometheus orbit requires gravitational assist from moon. Detailed analysis required to assess risk.	Med.	Med.	Low	Low

<u>Notes</u>

1. Daniel R. Coulter, Technology Program Overview Presentation to the NGST Standing Review Board, 1/14/98
2. John Mather, NGST Technology Harvard CfA Conference, 5/18/00
3. J. Cornelisse, Integral Field / Multi- Object Spectrograph for the NGST, LAS-NGST-IFMOS-004, 30/9/99
4. BOMEM Inc., SP-BOM-006/99 Rev. B, 10/13/99
5. NGST Science Instrument Technical Panel Report, 12/01/99
6. N/A: Not Applicable

System Hierarchy and Risk Factor Tree
Pre-Phase A



Assessment of Potential Outcomes - CCD Development

Scenario	Mission Impact ^	Satellite Impact ^	Technical Opportunity / Mission Impact Severity	Cost/Schedule Opportunity / Severity
Use UCB CCD 10.5 µm – Full performance	Scientific goals achieved	Baseline OTA (TMA 55) and spacecraft OK	High opportunity	High opportunity
Use UCB CCD 10.5 µm – Acceptable performance	Scientific goals achieved	Baseline OTA and spacecraft OK	Med. opportunity	Med. opportunity
Use UCB CCD 12.0 µm – Full performance	Scientific goals achieved	Preliminary OTA design available (TMA 59)	High opportunity	High opportunity
Use UCB CCD 15.0 µm – Full performance	Most science achieved; more complex operation; longer mission.	Baseline OTA and spacecraft need to be revisited. OTA size becomes a concern.	Low severity	Low cost impact (TBD)
Use commercial CCDs	Descoping required due to reduced charge transfer efficiency, poor I-band and Z-band quantum efficiency.	New optical imager concept needs to be developed. LEO orbit, thermal design, shielding are TBD options.	High to medium severity	Significant cost impact (TBD)

^ Outcome refers only to a failure of the development effort and not a failure of the CCDs in flight.

- Assessment of risk consequences to be completed by 4/1/01

Parametric Cost Estimate for Reaching TRL 6

- NASA Multivariable Instrument Cost Model with TRL (MICM-TRL)
  - Cost Drivers
    - Weight, Power, Data Rate, Schedule, Year of technology, Instrument Family, Mission Class
    - TRL

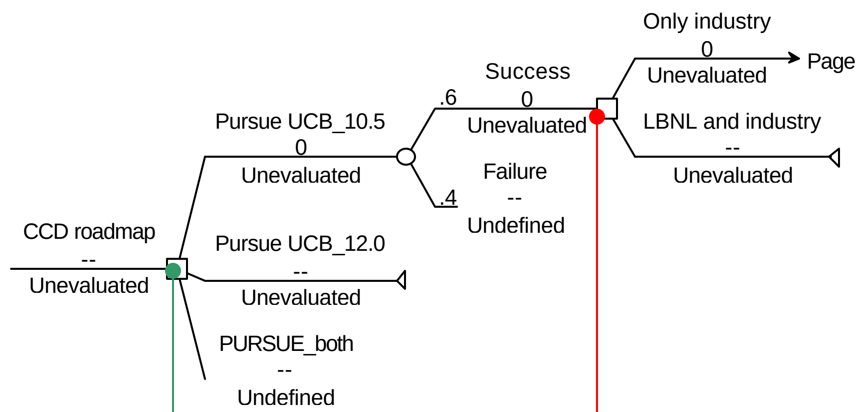
$$\text{Instrument Cost} = \Phi(\text{cost drivers}) * \text{TRL}^{-0.234}$$

- Use of MICM-TRL to estimate R&D cost
  - Illustrative example
    - Given instrument with TRL 3
    - Want to reach TRL 6
    - Estimated cost for building "flight-proven" instrument (TRL 9) : $20M

➢ Cost (TRL 3 - TRL 6) = (20/0.59)*(0.77 - 0.65) = $4.1M

Seems to provide credible estimate for R&D effort!

CCD Development Decision Tree
Partial



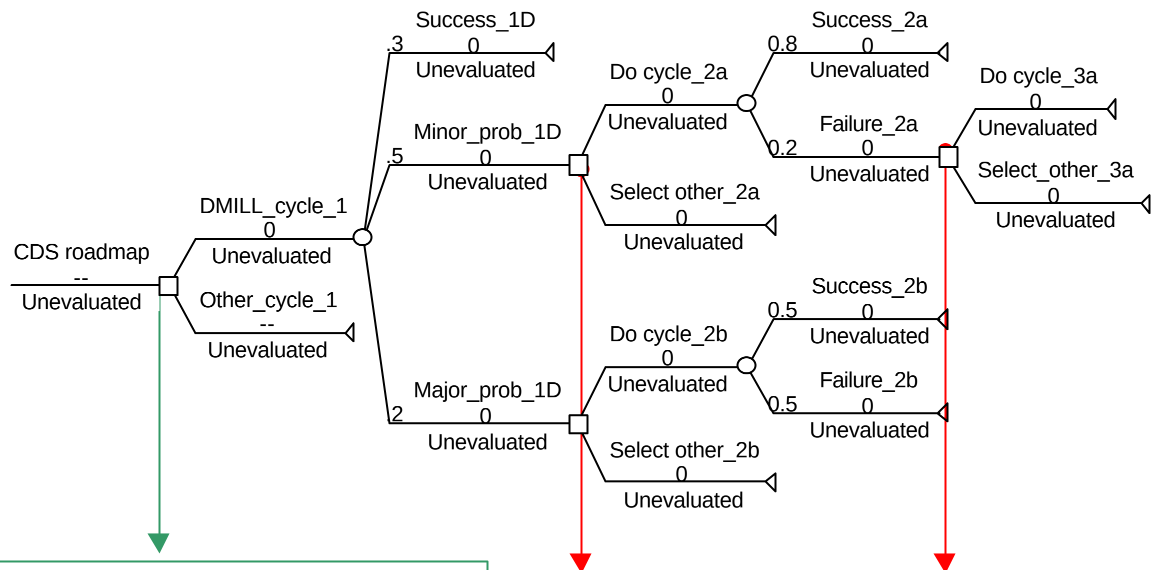
<u>Decisions made –12/00</u>

- Pursue both

<u>Decisions to be made / Drop-dead dates</u>

- Select technology & design: CD-1 5/02
- Select manufacturing option: CD-1 5/02

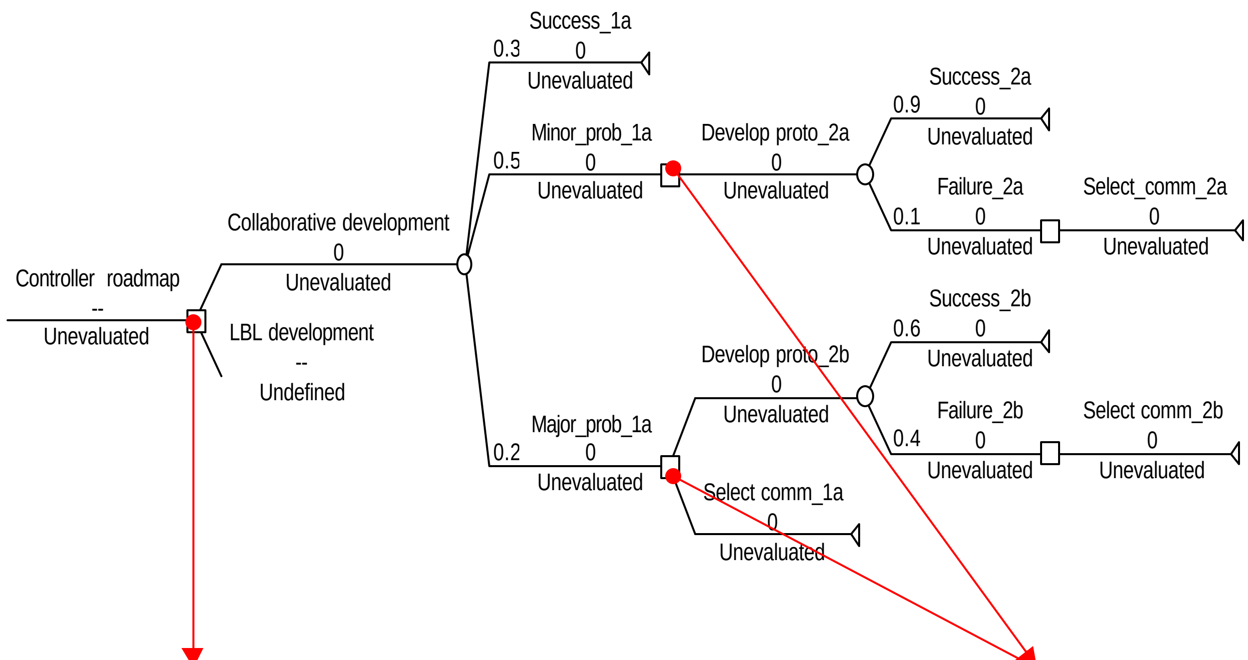
Correlated Double Sampler Development Decision Tree
Partial



<u>Decisions made - 12/00</u>
- Pursue 2 technologies in parallel
- DMILL cycle 1 partial success
- Other technology initiated in 2/01

<u>Decisions to be made / Drop-dead dates</u>
- Begin cycle 2: 10/01
- Select technology & design: 7/02

CCD Controller Development Decision Tree
Partial



Cycle 1 decisions / Drop-dead dates

- Begin cycle 1: 6/01
- Complete design 1: 01/02
- Fabricate prototype 1: 1/02
- Test prototype 1: 4/02

Cycle 2 decisions / Drop-dead dates

- Begin cycle 2: 10/02
- Complete design 2: 01/03
- Fabricate prototype 2: 1/03
- Test prototype 2: 4/03
- Select design: 6/03

- Decision trees for all high and medium risks to be completed by 10/1/01

Sample Benefits of Conceptual Design Phase Activities - To be completed by 1/10/01

	Preconceptual Phase		Conceptual Design Phase Activities			
Risk Driver	**Prob.**	**Impact**	**Activities**	**Budget $M**	***Prob. Of Success >=**	**Residual Risk**
Optical imager detectors	High	Unable to perform mission within cost & budget.	Successful demonstration of high yield & CCD performance in space environment	XX	85%	Low/med.

Data Handling	High	Unable to adequately scope operations.	Model data processing and handling.	YY	95%	Low

* Probability that TRL 6 or higher will be achieved and that design/engineering risk factors will be medium or low by the end of conceptual design phase given the planned activities.

Appendix A - OTA Technology Assessment by M. H. Krim

SNAP OTA Technology Assessment

Prepared by M. H. Krim
1/16/01

OTA is at high level of technology readiness. As indicated in chart below, no fundamental development needs were identified. Where TRL's are specified as '7' or '8', HST flight experience is judged to be equivalent to SNAP or to SNAP prototype. A TRL of '3' generally signifies that it an important area and that the analysis has not been done or should reinforced with an independent check.

The technology readiness levels (TRL's) of the OTA are summarized here. It is assumed the telescope operates at 'room temperature' and is designed to support a nominally 200K instrument section that is integrated subsequent to OTA thermal verification. The notional OTA is a 2.0m diameter f/10 system with an f/1.25 PM.

Global Risks and Related Technology Issues	**1/1/01**	**10/2/02**	**9/3/03**	**Reference**
Optical Design re. Wide Field Performance	3	6	6	Independent modeling yet to be done to verify optical design
Performance Robustness, i.e. Alignment Sensitivity	7	7	7	HST faced and solved similar problems
Stray Light and Performance Adequacy	3	6	6	Detailed modeling to verify warm telescope is OK is yet to be done
OTA Configuration and Interfaces	5	7	7	Concepts OK, details to design required
Instrument Section Configuration & Interfaces w/OTA	3	6	6	No fundamental problems foreseen but engineering and design yet to be done
Weight	7	7	7	Unusually LW techniques not required, no problems foreseen
ULE Substrate Producibility and Weight	7	7	7	Delivery schedule, not technical is principal risk. Similar to HST & others
Optical Fabrication, Metrology and Gravity Release	7	7	7	Less demanding than 2.4m HST, 0-g mount already proven on HST
Optical Coating (protected silver)	7	7	7	Already proven producibility and flight operation
Mounting, et al	7	7	7	Nothing unusual; experience from HST and others
6 DoF Mounting	7	7	7	HST (and other) experience
Alignment Stability (Structure)	7	7	7	HST (and other) experience
Mirror incl. Cryo Null Figuring	7	7	7	SIRTF and others

Mounting and Alignment	6	7	7	To be demonstrated by design in near future
Beam Directing Flat(s)	7	7	7	Small, already demonstrated on other systems
Filter Wheel Assembly	Insufficient requirements and configuration design information to evaluate at this time			
CFRP Materials Design and Fabrication	8	8	8	Demonstrated via HST and others, technology is mature
SM Support Structure	No			Several options available, no design or fabrication risk
Instrument Support Structure		problems		Similar in principle to HST focal plane structure, designs yet to be done
Integrating Structure			anticipated	Similar in principle to HST, design specifics yet to be done
Jitter and Micro-Dynamics	6	6	6	Less sensitive than HST in terms of SM jitter
Alignment Stability (thermal)	6	8	8	Less stressful than and already demonstrated via HST, and others
External Baffles	8	8	8	Routine, based on HST experience
Viewport Door	8	8	8	Similar to other systems, engineering and design yet to be done
OTA Passive Alignment Stability	3	6	6	HST experience, yet to be modeled for this system in particular
OTA/Instrument Mounting Interface Stability	3	6	6	Designs yet to be done but similar in concept to HST
PM Heater Control	8	8	8	Flight proven on HST
Cold Instrument Section	Insufficient requirements and configuration design information to evaluate at this time			
Dewar	5	5	5	Conventional design; no breadboard or development testing needed
Optical Train Testing	6	6	6	Full aperture A/C flats available
Overall OTA Verification	8	8	8	Experience with similar performance and similar size systems
OTA Image Location & Data Transfer to Instrument	3	6	6	Details to be developed, similar to HST, NGST Observatory-class systems
OTA/SI Integration and Verification	6	6	6	HST experience including in-flight change-outs, SNAP designs forthcoming

OTA TRL Matrix based on the above evaluation

Telescope	1/1/01	10/2/02	9/3/03

Image Quality	3	6	6
Stray Light and Self-Emission	3	6	6
Primary Mirror Assembly	7	7	7
Other Optics	7	7	7
Structure	7	7	7
Thermal Stability & Control	3	6	6
Integration & Verification	6	6	7

In conclusion, the OTA is free of fundamental technical risks that might require breadboard or developmental testing. Where there are 3's, it signifies that the modeling and/or analysis, or specific design details have not yet been addressed; but no problems are anticipated in these areas.